MODELED CHANGES TO GREAT SALT LAKE SALINITY FROM RAILROAD CAUSEWAY ALTERATION

James White
Graduate student
Utah State University
Watershed Science Department
whitej33@gmail.com

Co-authors:
Sarah Null
David Tarboton

Overview

1) Brief introduction and history of Great Salt Lake (GSL) and Union Pacific Railroad (UPR) causeway
2) Model methods
    1) USGS Great Salt Lake Fortran Model
    2) Different model runs
    3) Limitations of model
3) Results
    1) Validation of methods
    2) Results of each model run
4) Conclusions

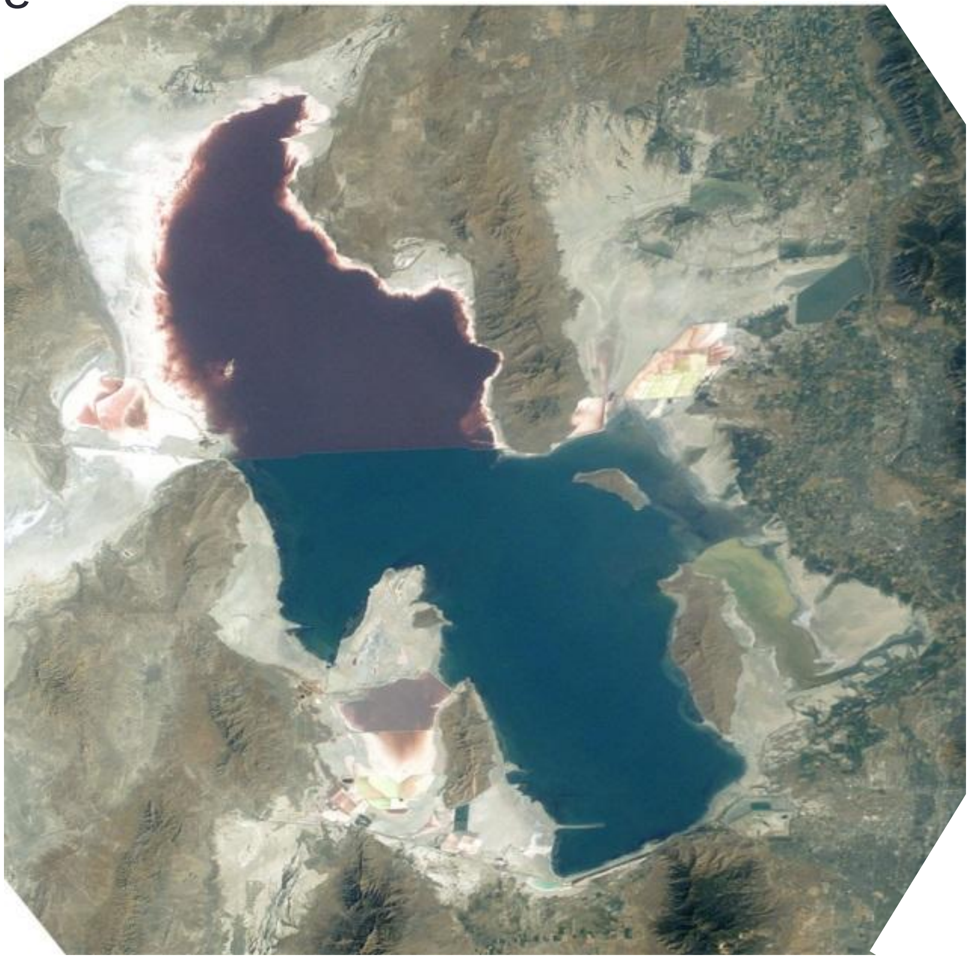
From June 2014 report- "Modeled changes to Great Salt Lake salinity form railroad causeway alteration"

5) Additional UPR bridge designs
6) Questions

Model runs not in report or previous presentation (8/6)

Great Salt Lake

- Remnant of historic Lake Bonneville
- Largest saline lake in Western Hemisphere
- Fourth largest saline lake in World
- Contributes $1.3 billion to local/regional economy
- Vital link in Pacific flyway
- Simple, but very productive food-web



Great Salt Lake

Surface inflow ~ 64%

Groundwater ~ 3%

Direct precip ~ 33%

~ 100%

Major surface inflows:

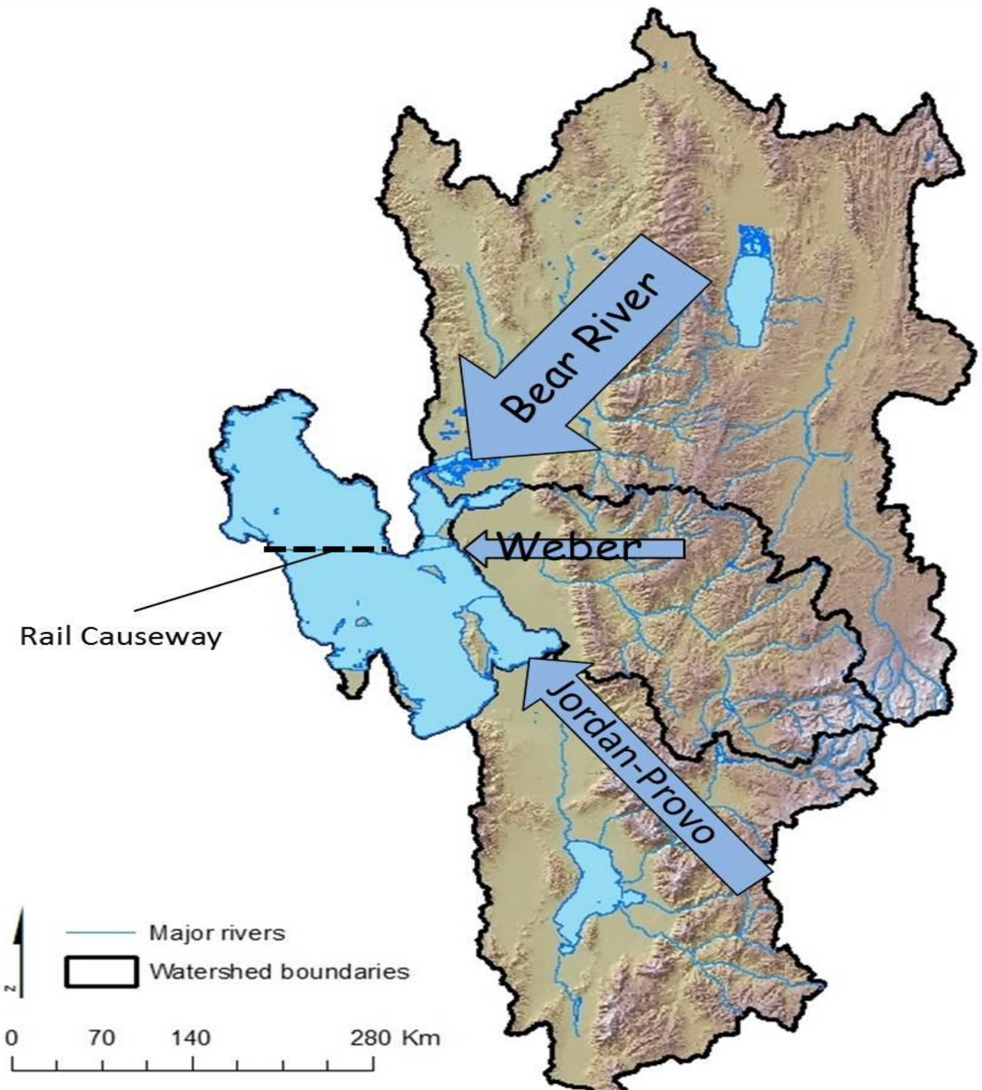
Bear River ~ 55%

Weber River ~ 12%

Jordan River ~ 26%

Ephemeral streams ~ 7%

~ 100%



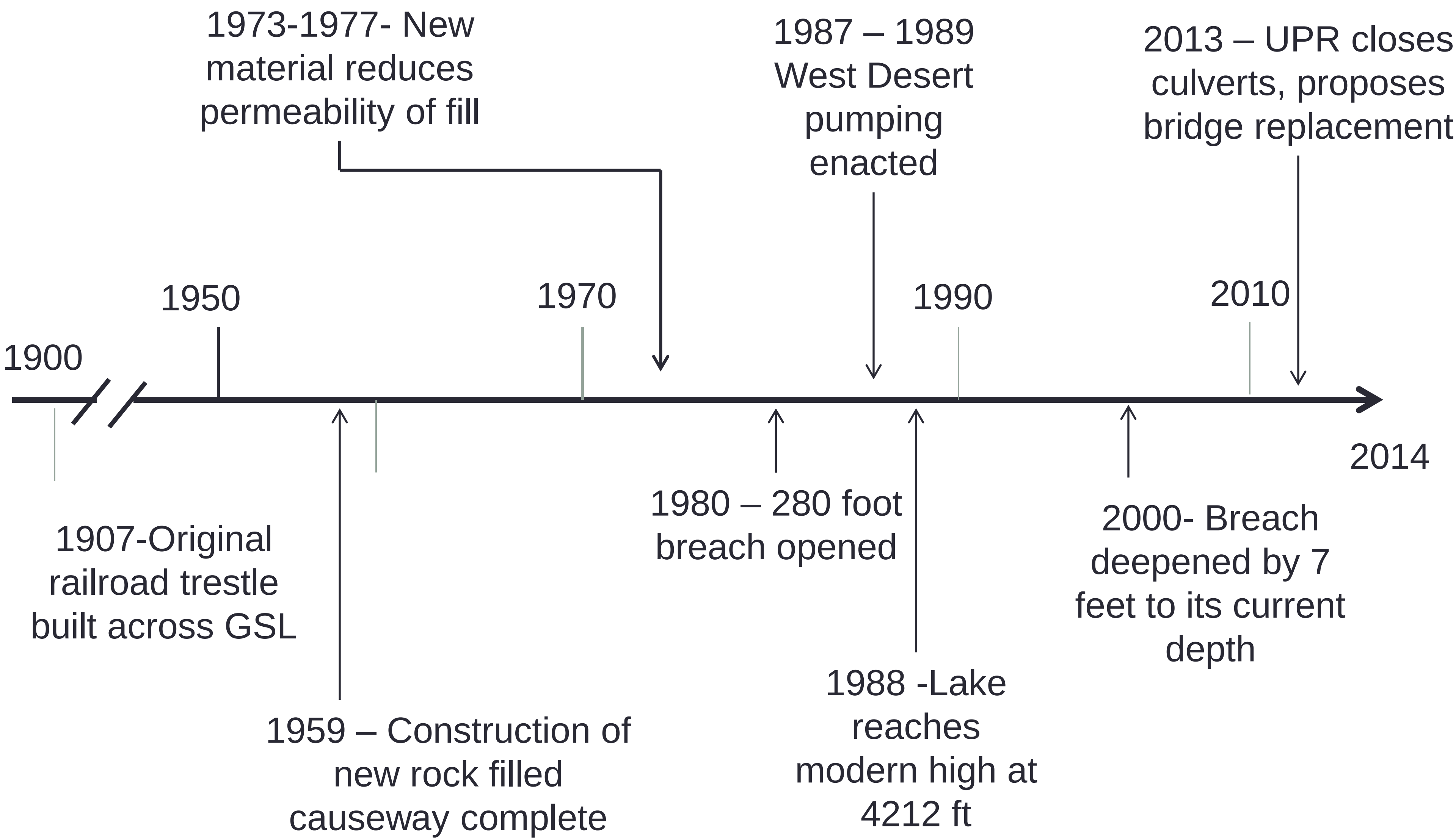
Causeway on Great Salt Lake

- Built in 1959 by Union Pacific Railroad (UPR)
- Two 15 ft wide culverts included to allow boat passage
- 280 ft “breach” added in 1980 to alleviate flooding
- Effectively separates Gilbert Bay (south arm) and Gunnison Bay (north arm)
- Built on soft lake sediments
  - Slowly subsided over time
- 95% of incoming freshwater enters south arm

Causeway on GSL

- Net export of salt from south to north
- Significant salinity gradient between north and south arm
  - North arm often at or near saturation (350 g/L)
  - South averages 142 g/L since 1966
- Ecology differs
  - North too saline for significant populations of brine shrimp
    - Dominated by red algae and archaea
  - South usually provides appropriate salinity for brine shrimp and brine flies
- Creates “deep brine layer” in south arm

Causeway on GSL



Modeling Methods

Modeling Methods - USGS GSL Fortran Model

- First developed in 1973 (Waddel and Bolke)

- Updated in 1997 (Wold et al.)
  - Includes culvert and breach flow calculations

- Most recent USGS update in 2000 (Loving et al.)
  - Developed trapezoidal calculations
  - Developed submerged flow calculations
  - Updates subsidence data on causeway

- Our Updates
  - Changes mainly to improve usability and flexibility of model
  - Ran simulations from 1966-2012
  - Includes proposed bridge design and other alternatives

Modeling Methods - USGS GSL Fortran Model

How model works:

- Model uses a “mass balance” approach to calculate changes of water volume and salt load at each time interval
- Flow through culverts and breach calculated by equations developed by Wold et al. (1997)
- Input data from USGS, OSU Prism, and Loving et al.

Modeling Methods - USGS GSL Fortran Model

Initial conditions

Each arm:
- Mineral loads
- Lake elevation

Monthly Inputs

Streamflow
USGS Streamflow Data for:
- Bear River
- Jordan River
- Weber River

Evaporation
Calculated via mass balance (more accurate than meteorological equations)

Direct Precipitation
Obtained from Oregon State University PRISM program

Updated USGS Great Salt Lake Model

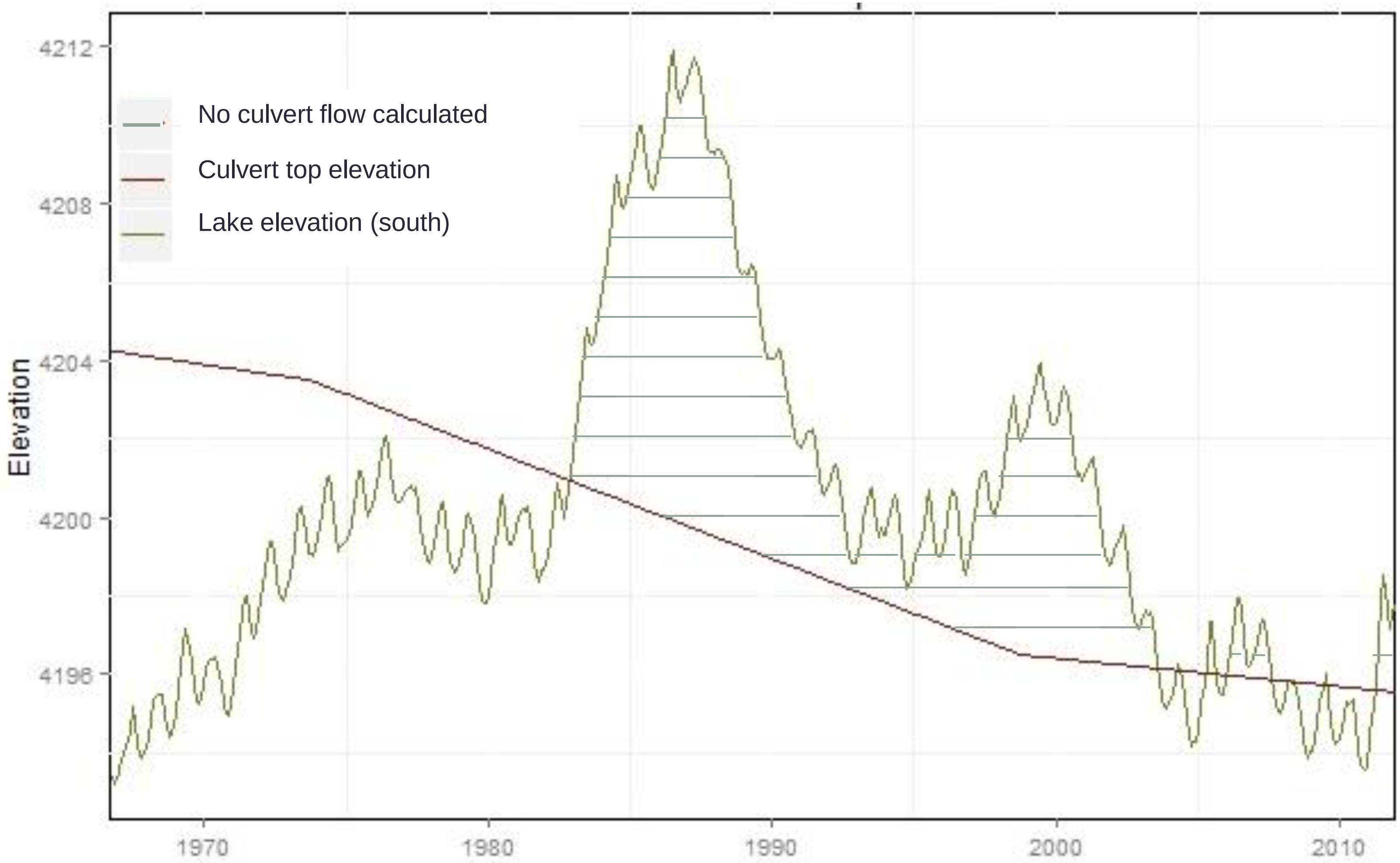
Monthly aggregated outputs (each arm):
- Lake elevation/volume
- Mineral load
- Mineral concentration (salinity)
- Flow through openings

Model limitations

- Flow through culverts assumed zero when submerged
  - More accurate than using equations developed by Loving et al. (2000) due to blockage of culverts
- Assumes homogenous salinity in each arm
- Does not track deep brine layer

Photo: Jacobs Associates

Model limitations



Different model runs

All models use identical climate conditions

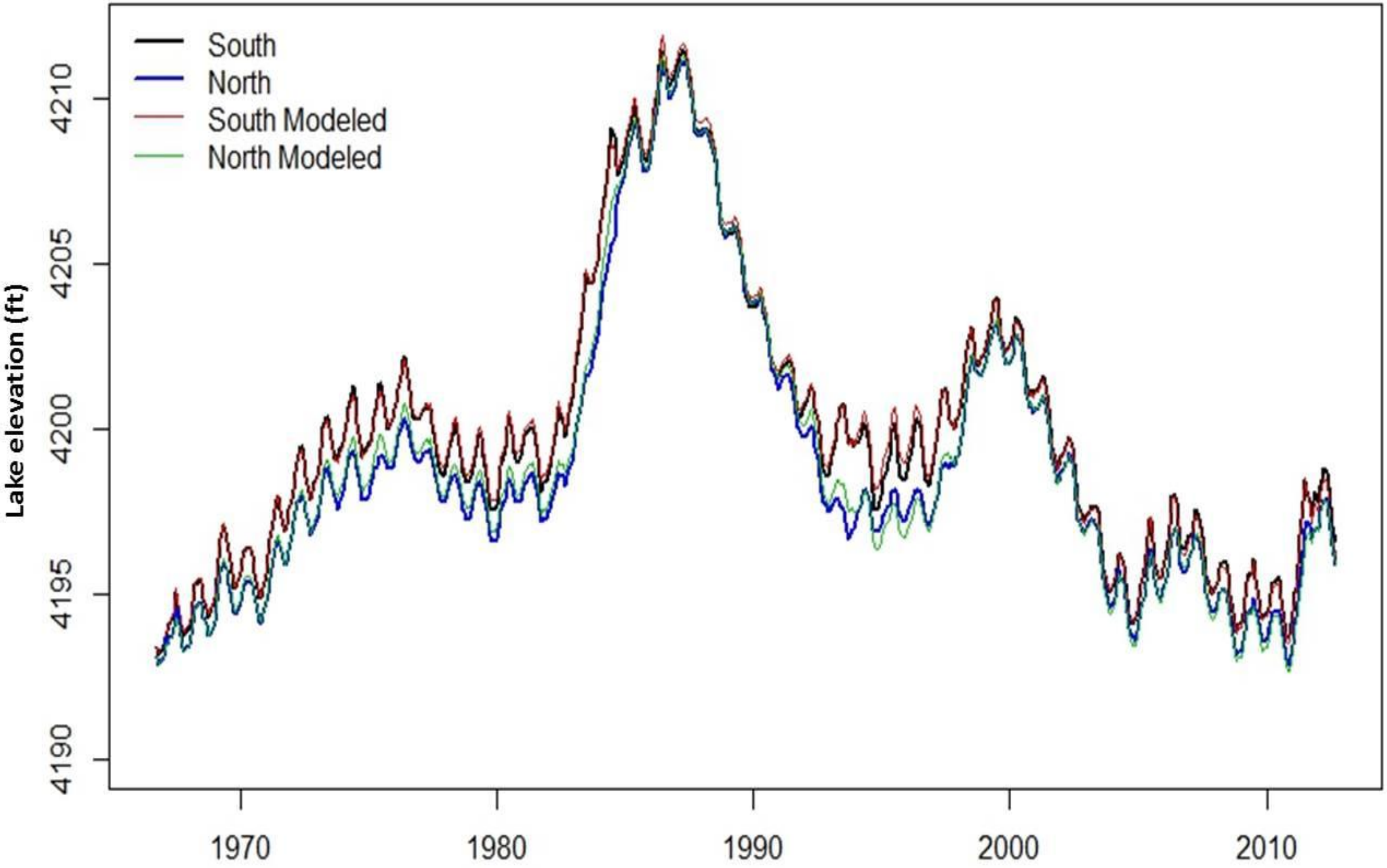
- “Historical” – uses historical climate data to evaluate model’s ability to replicate measured data
- “Proposed Bridge” Identical to historical, but culverts and been replaced with proposed bridge specifications
- “Current condition” – Causeway condition as of March, 2014 – culverts closed, breach deepened, causeway fully subsided
- “Whole Lake” – Theoretical single salinity lake, as if no causeway present
- Sensitivity analysis - +/- 20% bridge length, 60/180’ rectangular bridge

Different Model runs

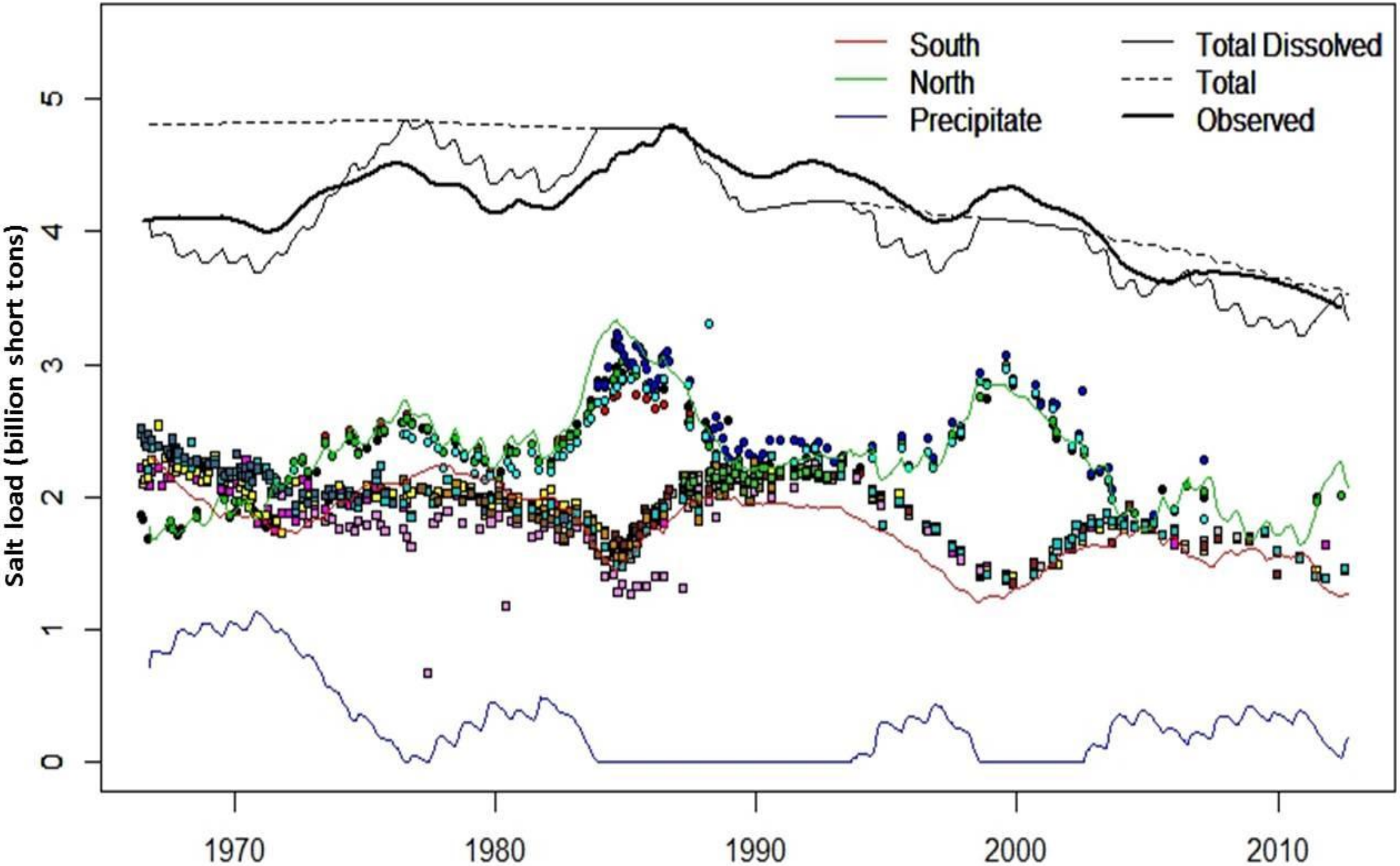
- Updated (since 8/6) to include additional bridge designs outlined in UPR report

Model Results - validation

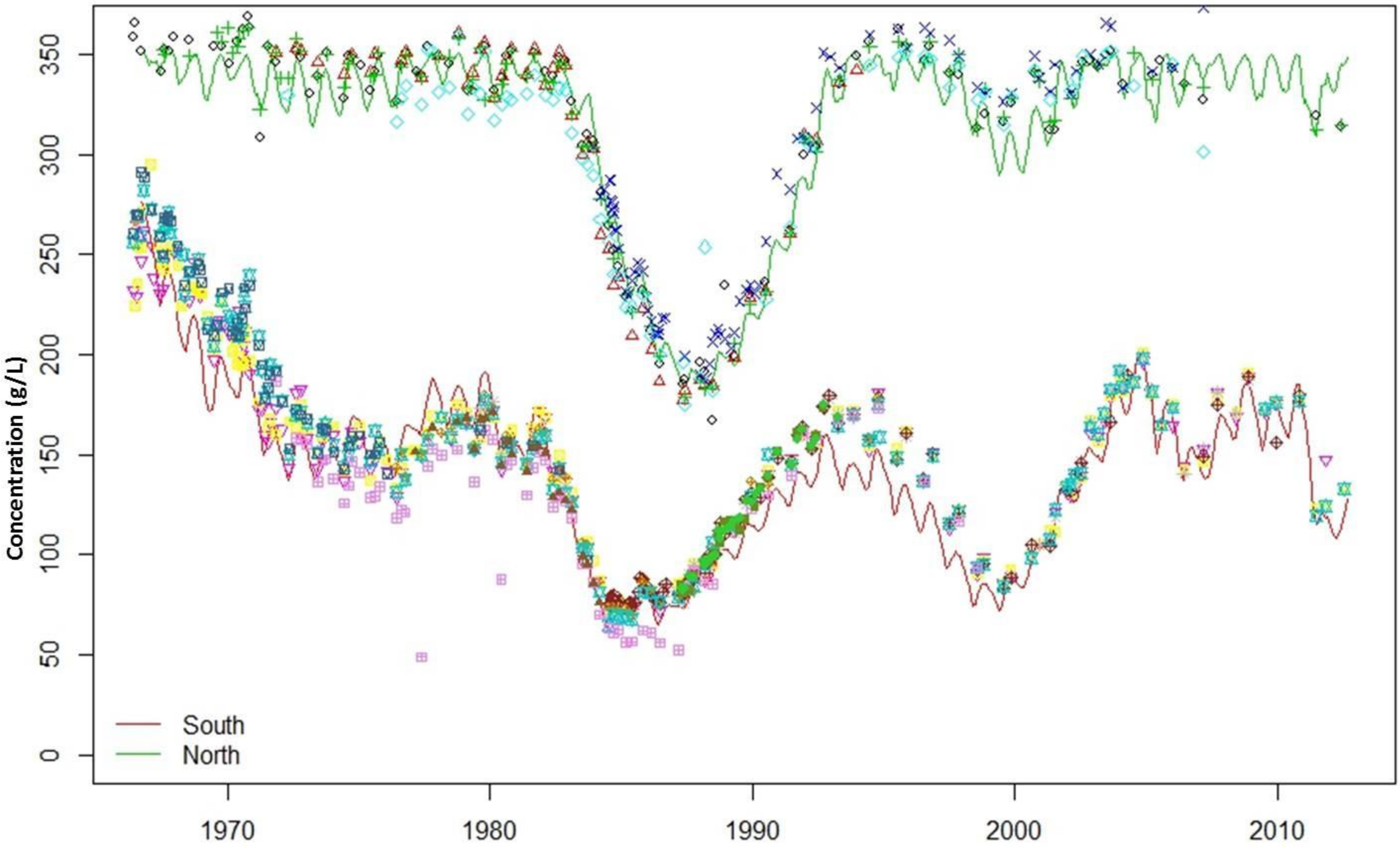
Model Results - validation



Model Results - validation



Model Results - validation



Model results - validation

Statistical validation:

Nash-Sutcliffe Efficiency (NSE)					
Level		Salinity		Load	
North	South	North	South	North	South
0.99	0.99	0.94	0.89	0.78	0.36

NSE – unitless value, ranging from 0-1.
0 = zero correlation
1 = perfect model fit

Model results - validation

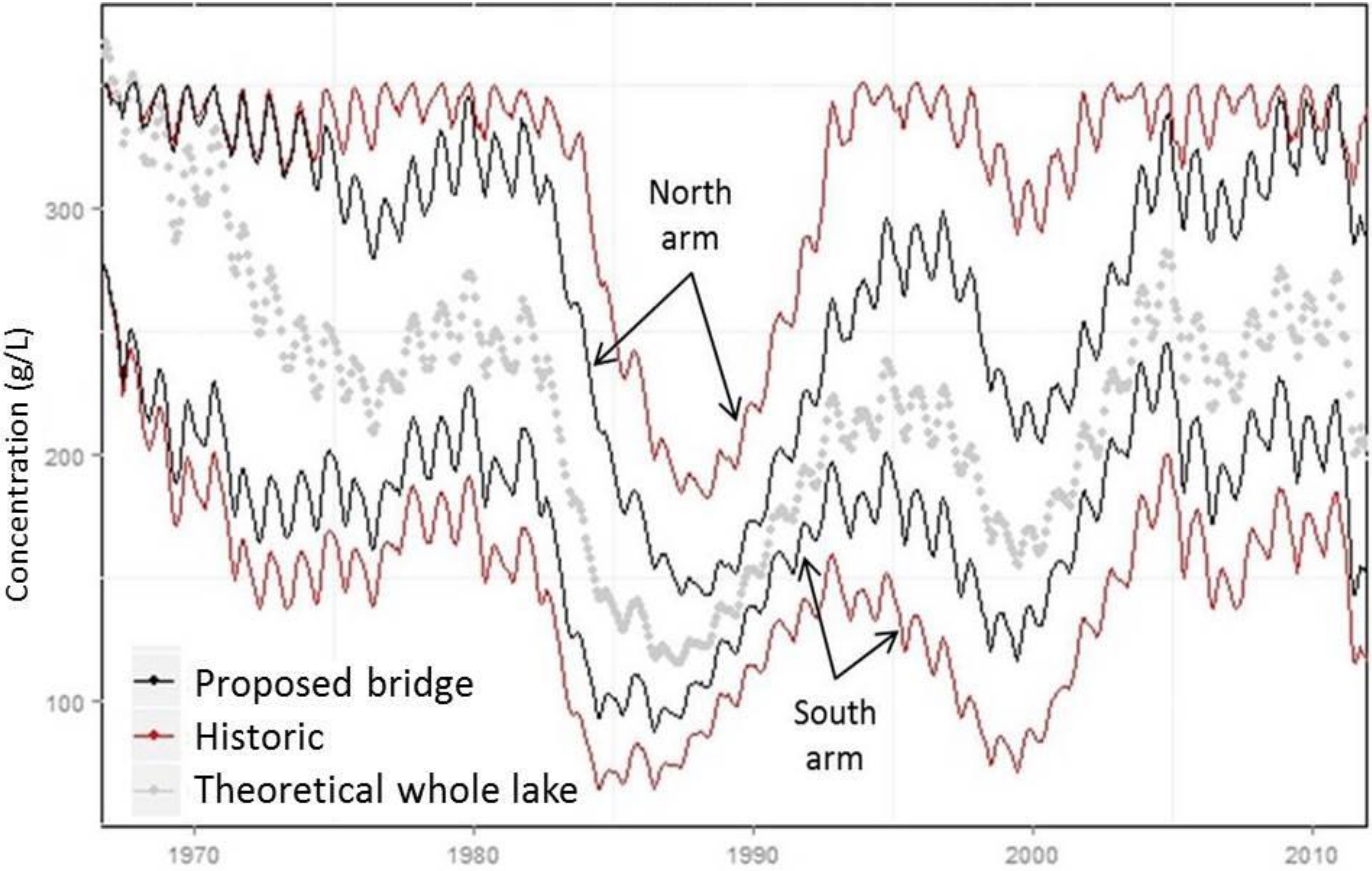
Statistical validation:

Nash-Sutcliffe Efficiency (NSE)					
Level		Salinity		Load	
North	South	North	South	North	South
0.99	0.99	0.94	0.89	0.78	0.36

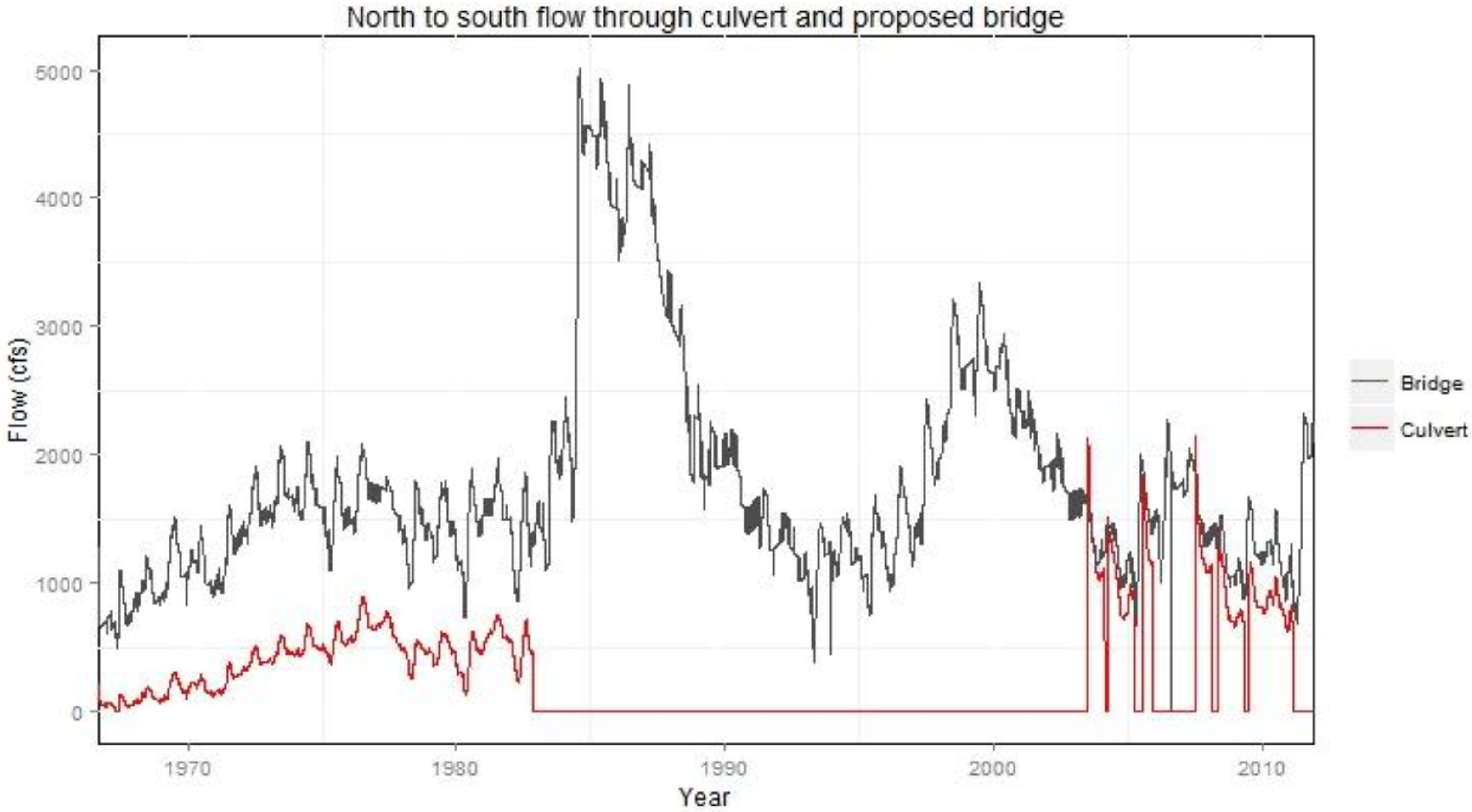
Attributed to:

1) No flow when culverts submerged
2) Potential small overestimate of load loss to West Desert
3) Imprecise historical data – calculated, not measured

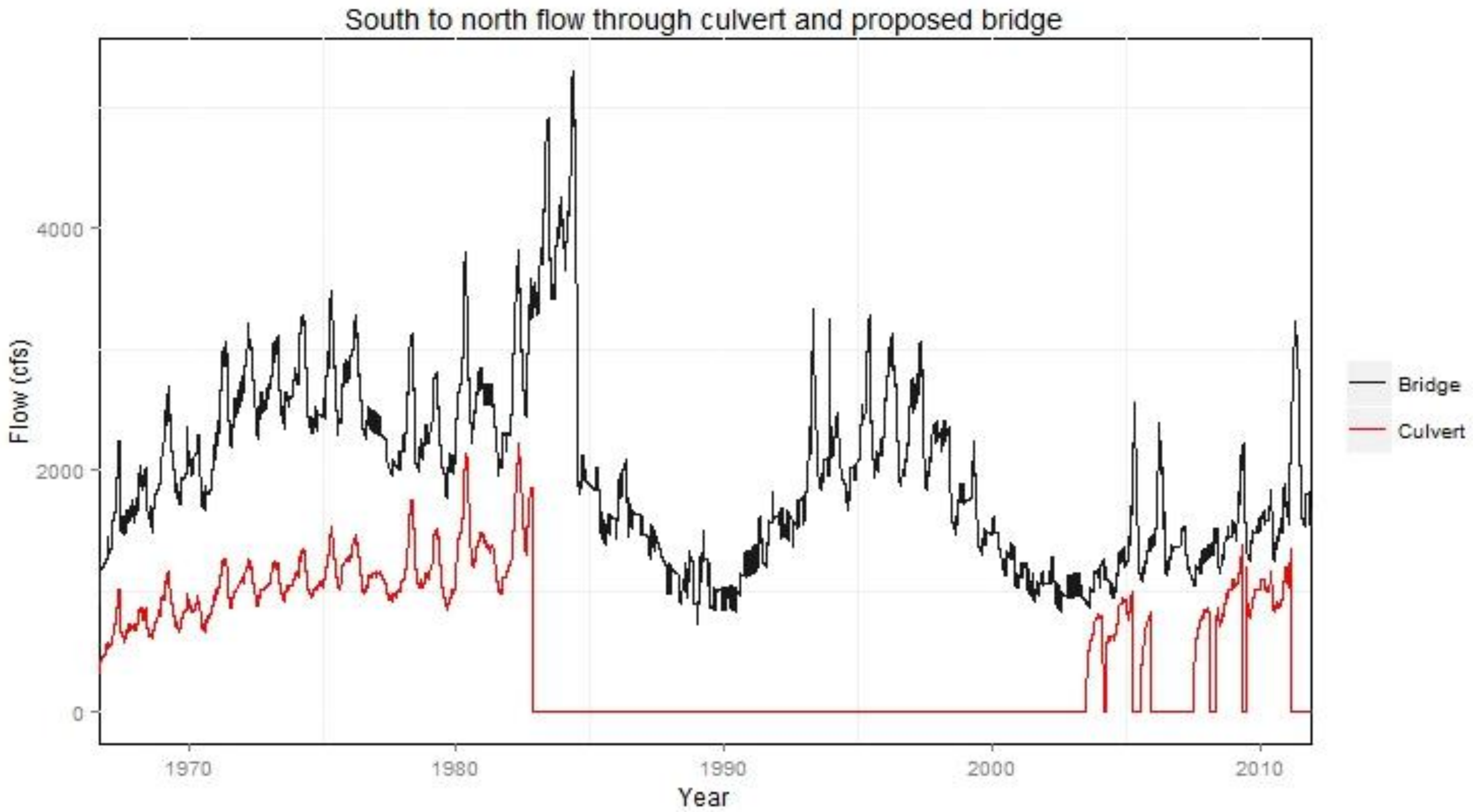
Model results – proposed bridge



Model results - proposed bridge

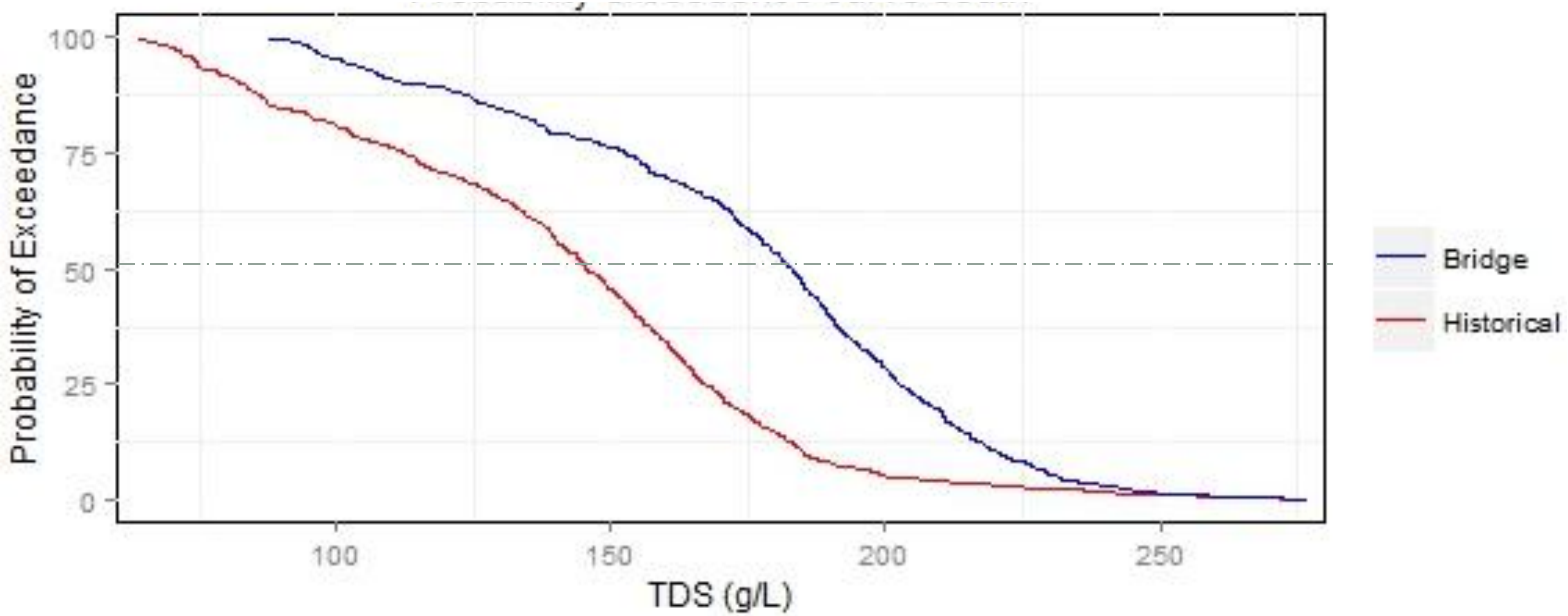


Model results - proposed bridge



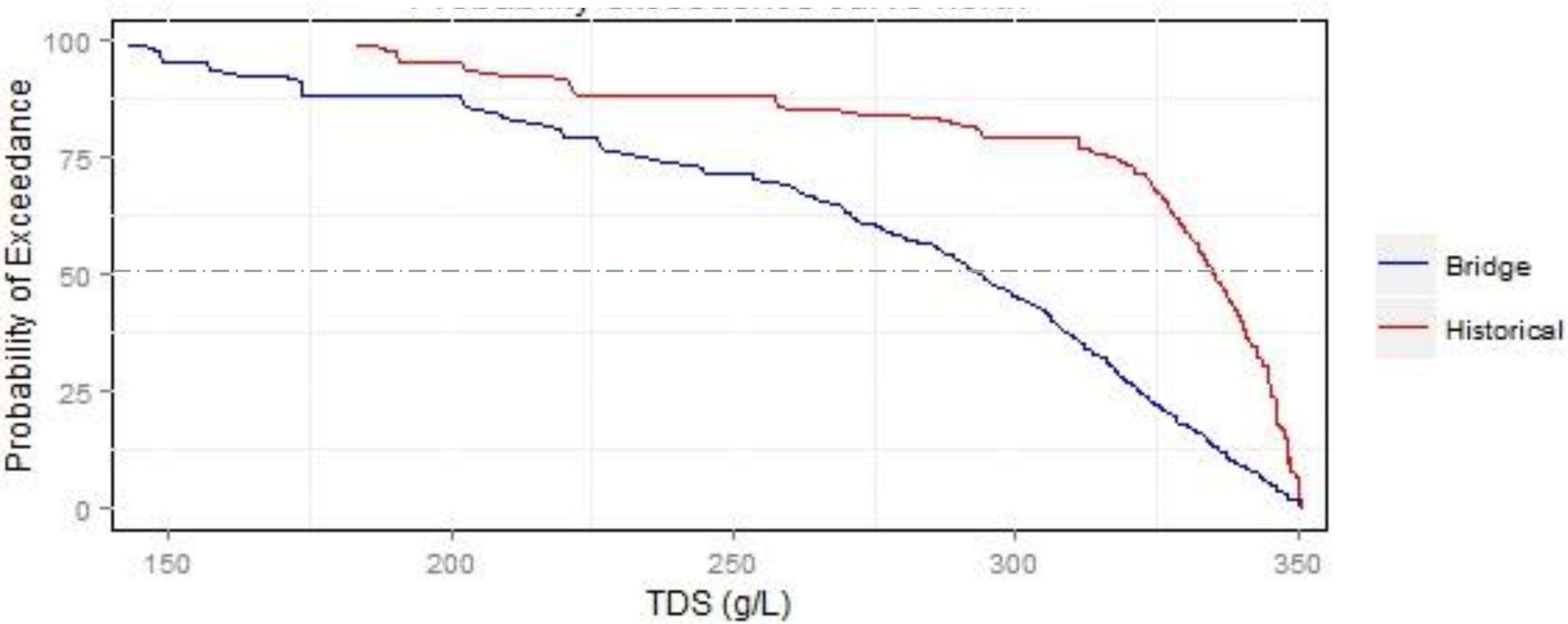
Model results - proposed bridge

Probability of exceedance curve south

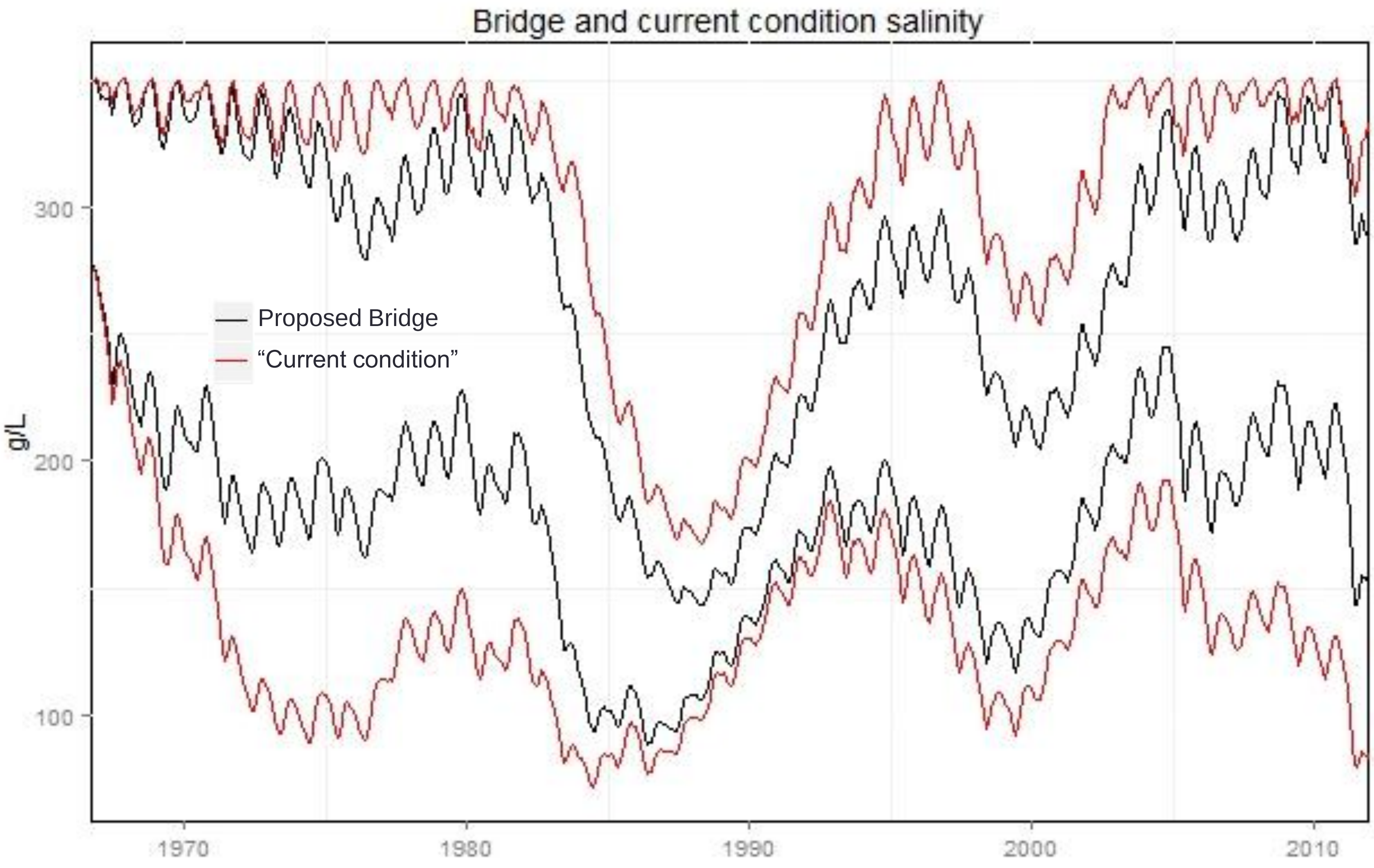


Model results - proposed bridge

Probability of exceedance curve north



Model results – “current condition”

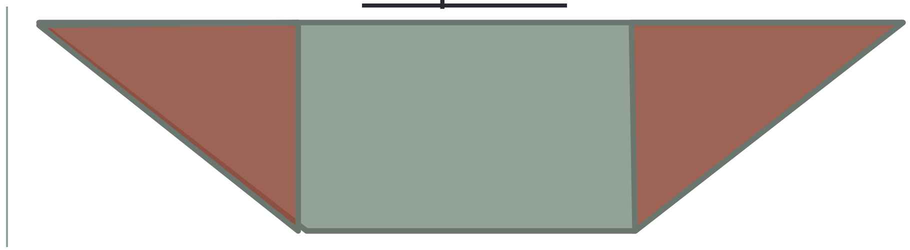


Model results – bridge design analysis

Model results – bridge design analysis

Proposed

38 ft



*All design top and bottom elevations are the same

Maintain shape adjust length

+ 20% length

38 ft

- 20% length

Adjusting shape

180 ft rectangle

38 ft

60 ft rectangle

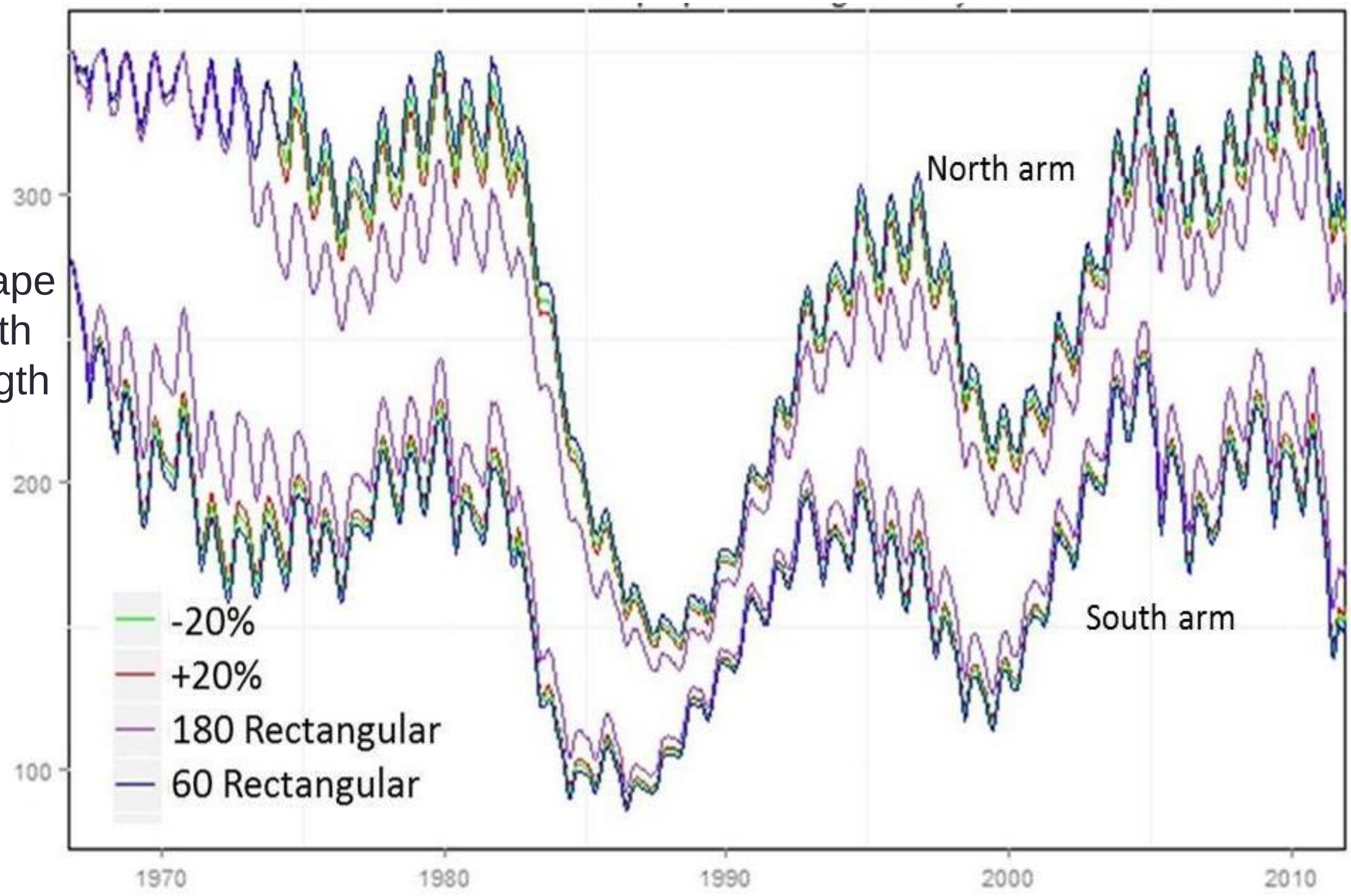
Model results – bridge design analysis

Four different designs:

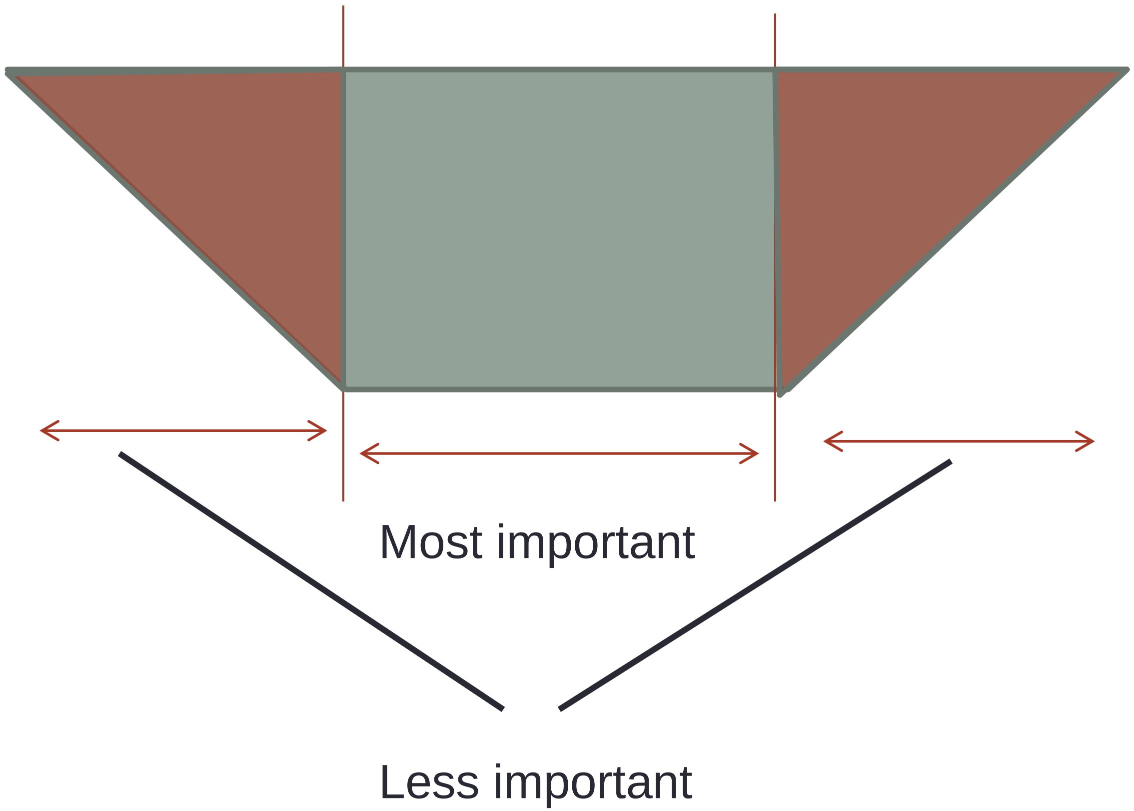
Maintain trapezoidal shape
1. Increase 20% length
2. Decrease 20% length

Rectangle shape
3. 60 foot rectangle
4. 180 foot rectangle

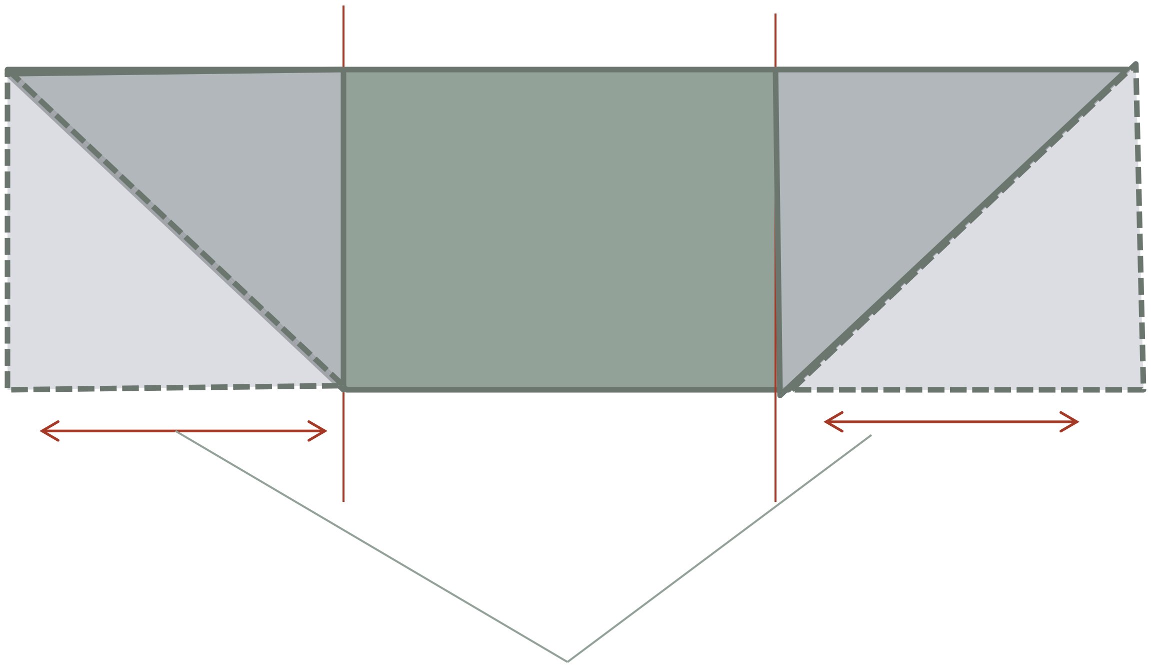
Bridge design sensitivity analysis salinity



Bridge design sensitivity results



Bridge design sensitivity results



More area at greater depth significantly increases flow

Model results –statistics

	Model Run	Mean salinity North (g/l)	Max salinity North (g/l)	Min salinity North (g/l)	Mean salinity South (g/l)	Max salinity South (g/l)	Min Salinity South (g/l)
	Historical	317	351	183	142	276	64
	Subsided	307	351	168	132	276	72
	Proposed Bridge	276	351	143	176	277	88
	Whole Lake	222 (mean)		351 (max)		115 (min)	
sensitivity analysis	**Bridge + 20% length**	275	351	142	177	277	88
	Bridge -20% length	278	351	144	175	277	87
	60ft rectangular bridge	282	351	147	172	277	86
	180ft rectangular bridge	257	350	134	189	278	93

Conclusions

- Updated USGS causeway model effectively replicates historic conditions (high model confidence)
- Proposed bridge reduces north arm salinity 41 g/L, on average compared to historic culverts
- Proposed bridge increases south arm salinity 34 g/L, on average compared to historic culverts
- Current (2014) condition results in less flow exchange and greater salinity differences compared to historic causeway condition and proposed bridge
- Shape of bridge more important than size
  - Trapezoid’s triangular sides not as important as middle rectangle
  - Consistent with Loving et al. analysis of design of breach

Additional UPR bridge designs

Additional bridge designs

Figure 1. Alternative Bridge Sizes

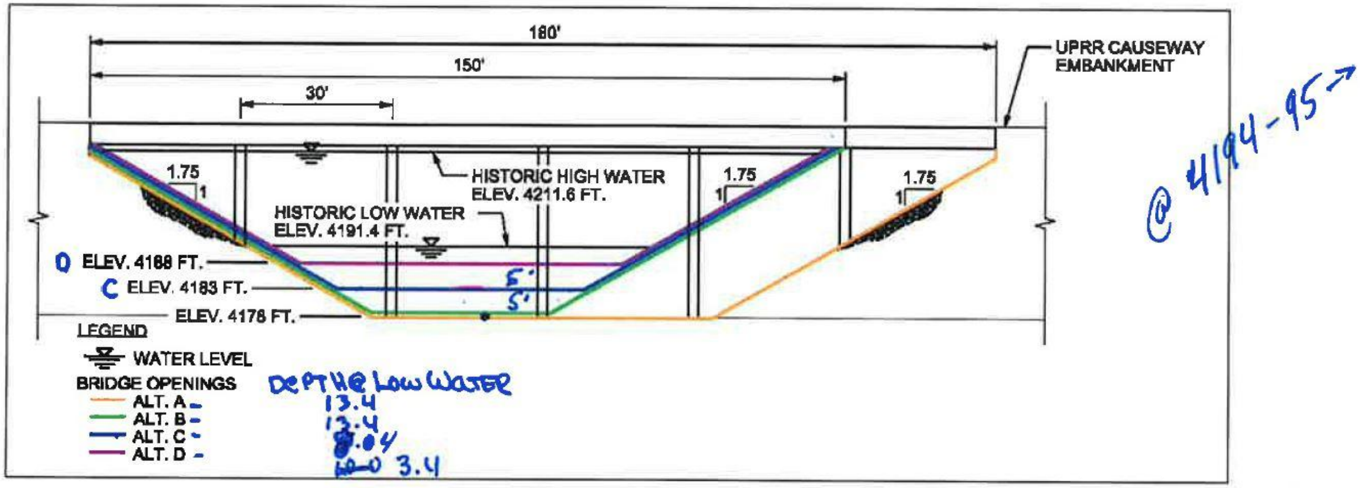


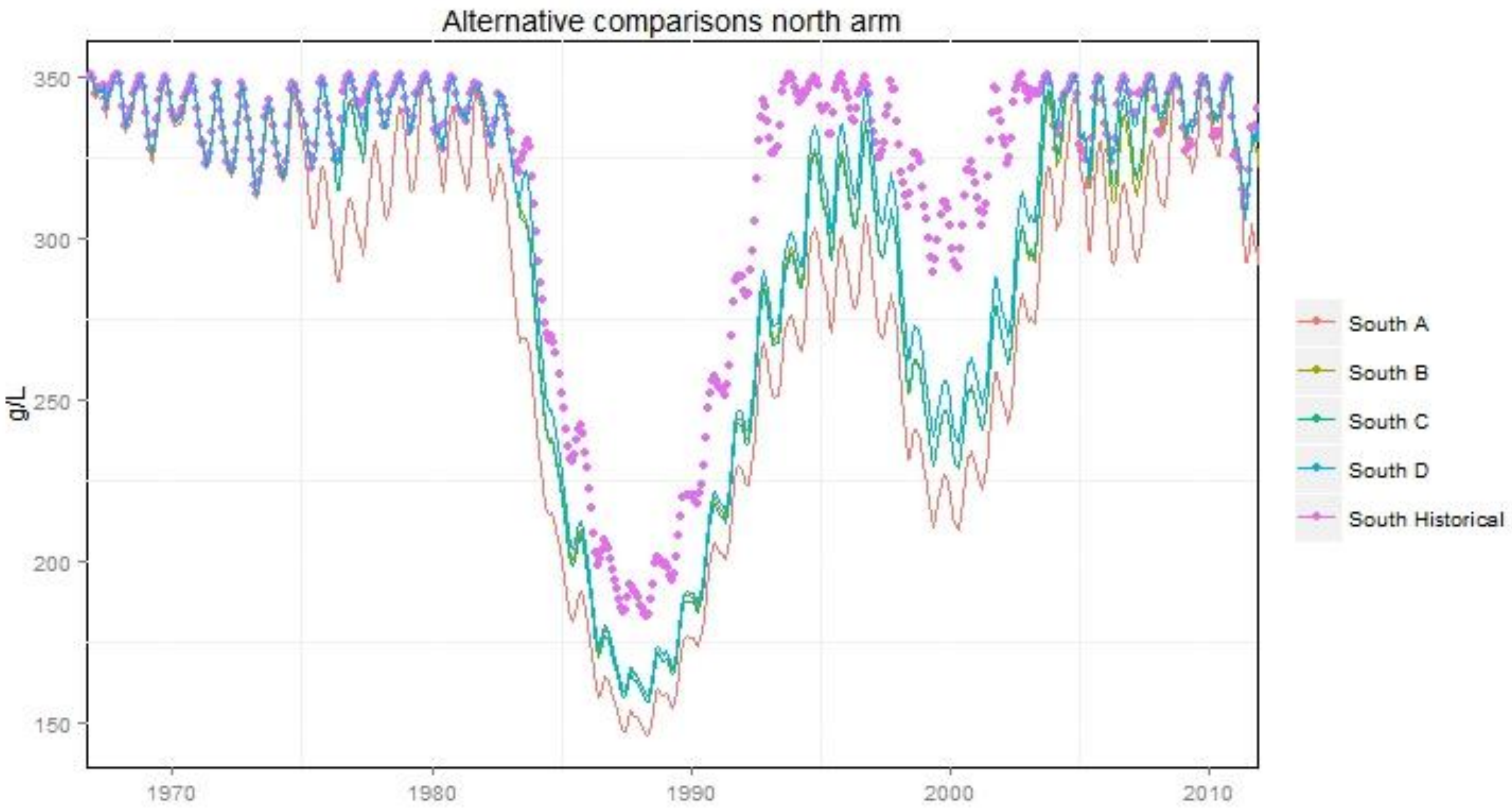
Table 2. Summary of Alternative Bridge Geometry Parameters

in feet

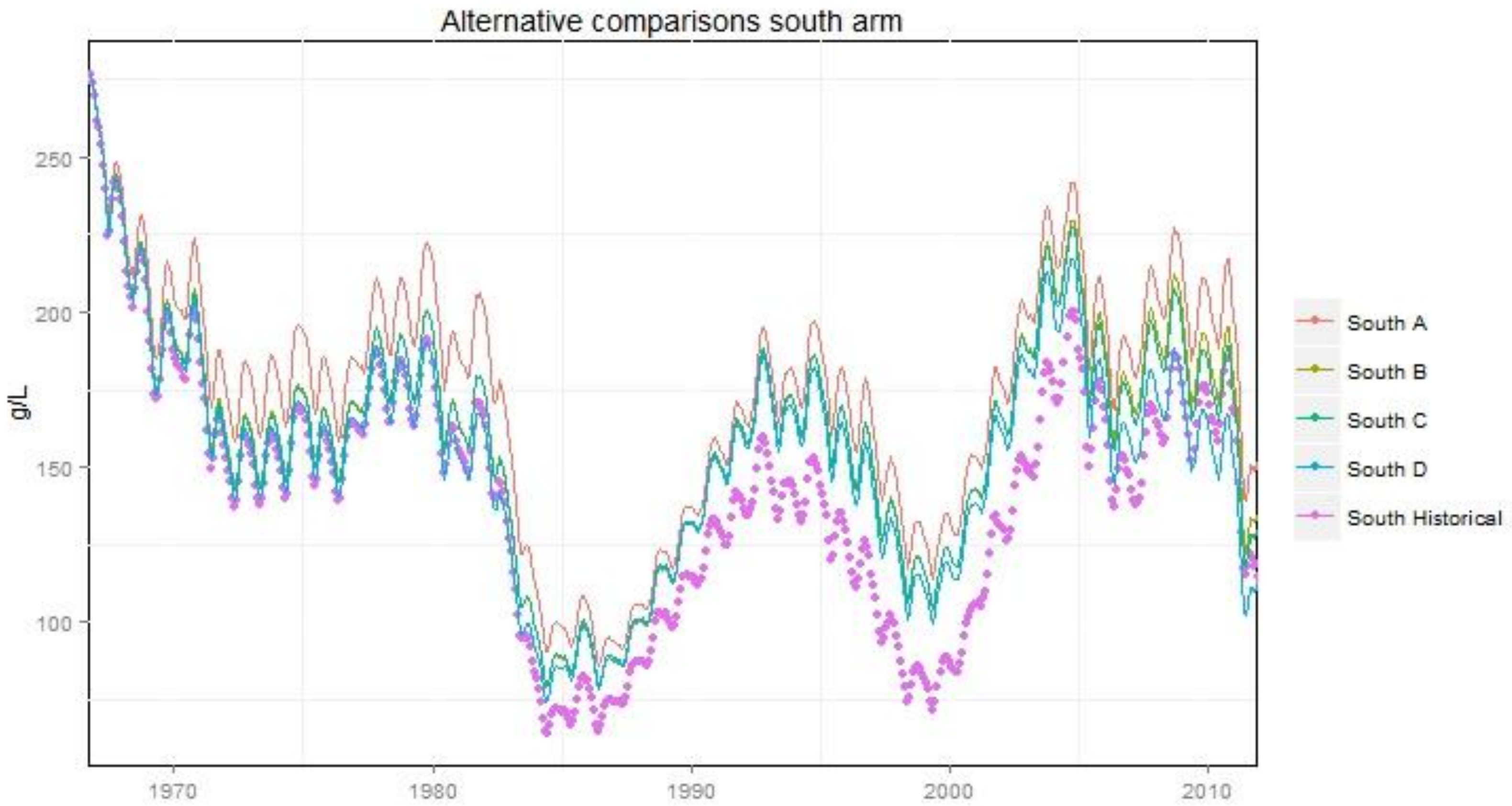
Alternative	Top Width	Bottom Width	Channel Bottom Elevation (NGVD 29)	Low Chord Elevation (NGVD 29)	Increase in Width per Increased Foot of Elevation
A	180	61	4,178	4,212	3.5
B	150	31	4,178	4,212	3.5
C	150	49	4,183	4,212	3.5
D	150	66	4,188	4,212	3.5

Table and figure from UPR Bridge Evaluation Report

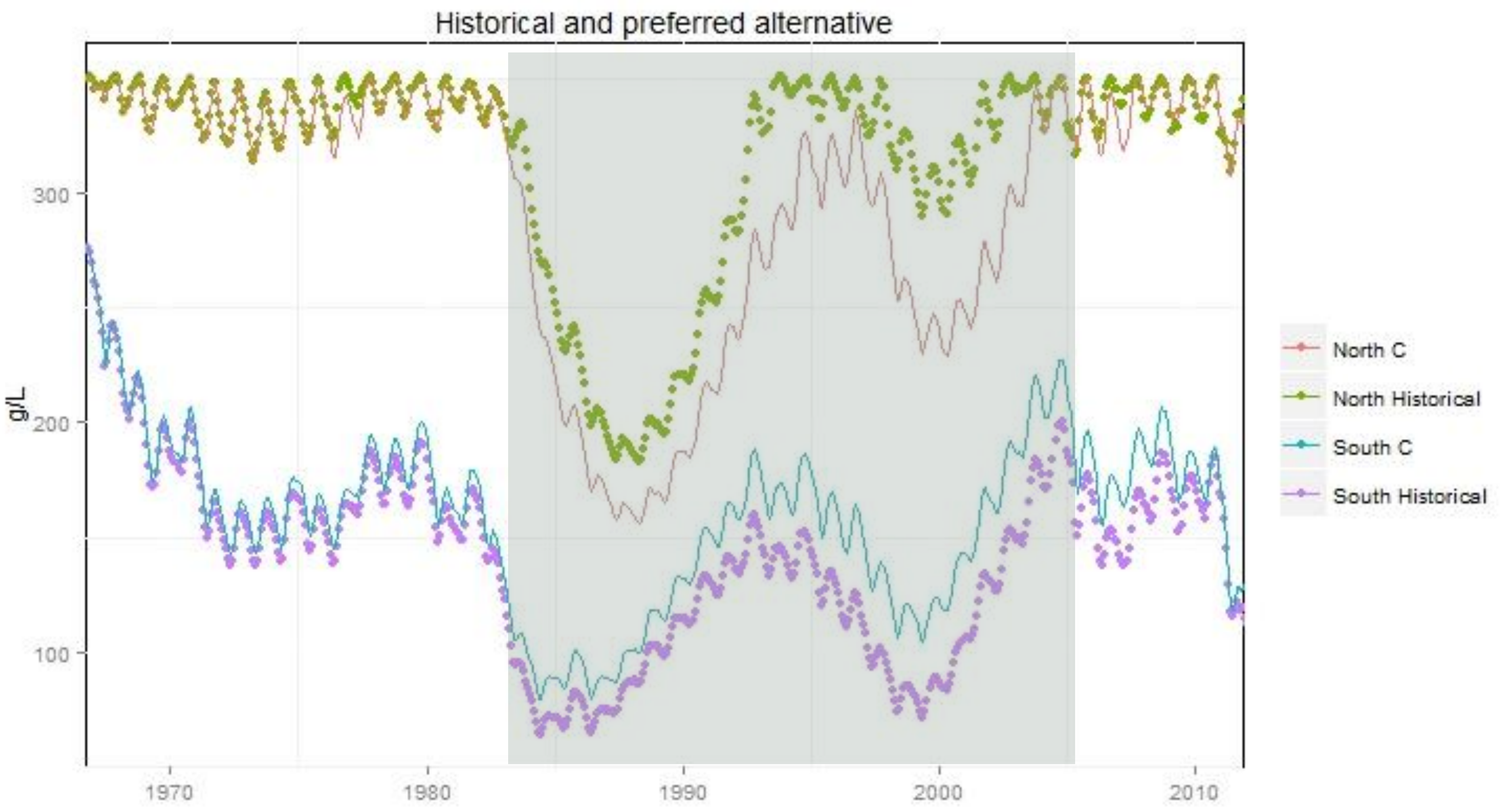
Additional bridge designs



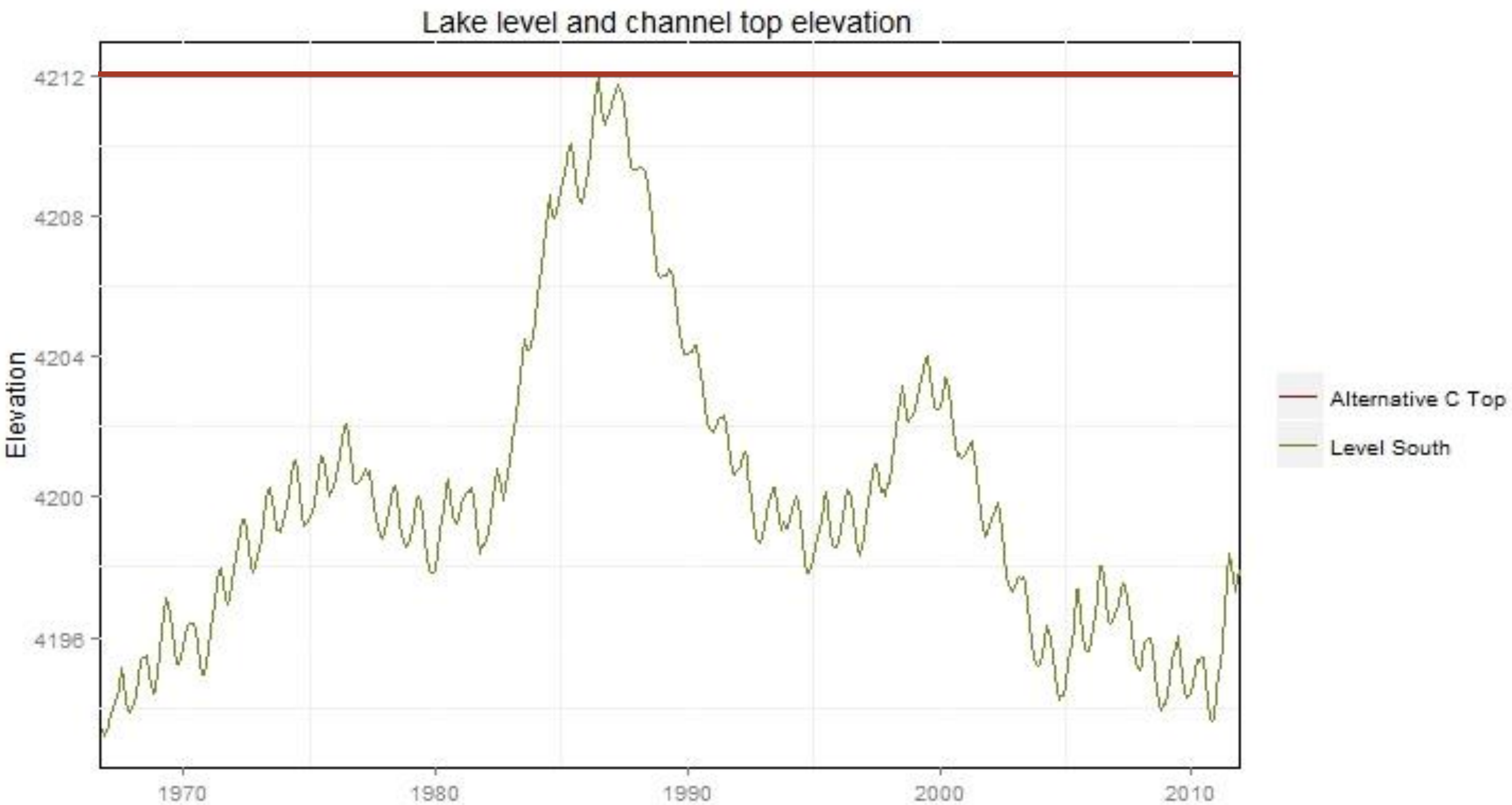
Additional bridge designs



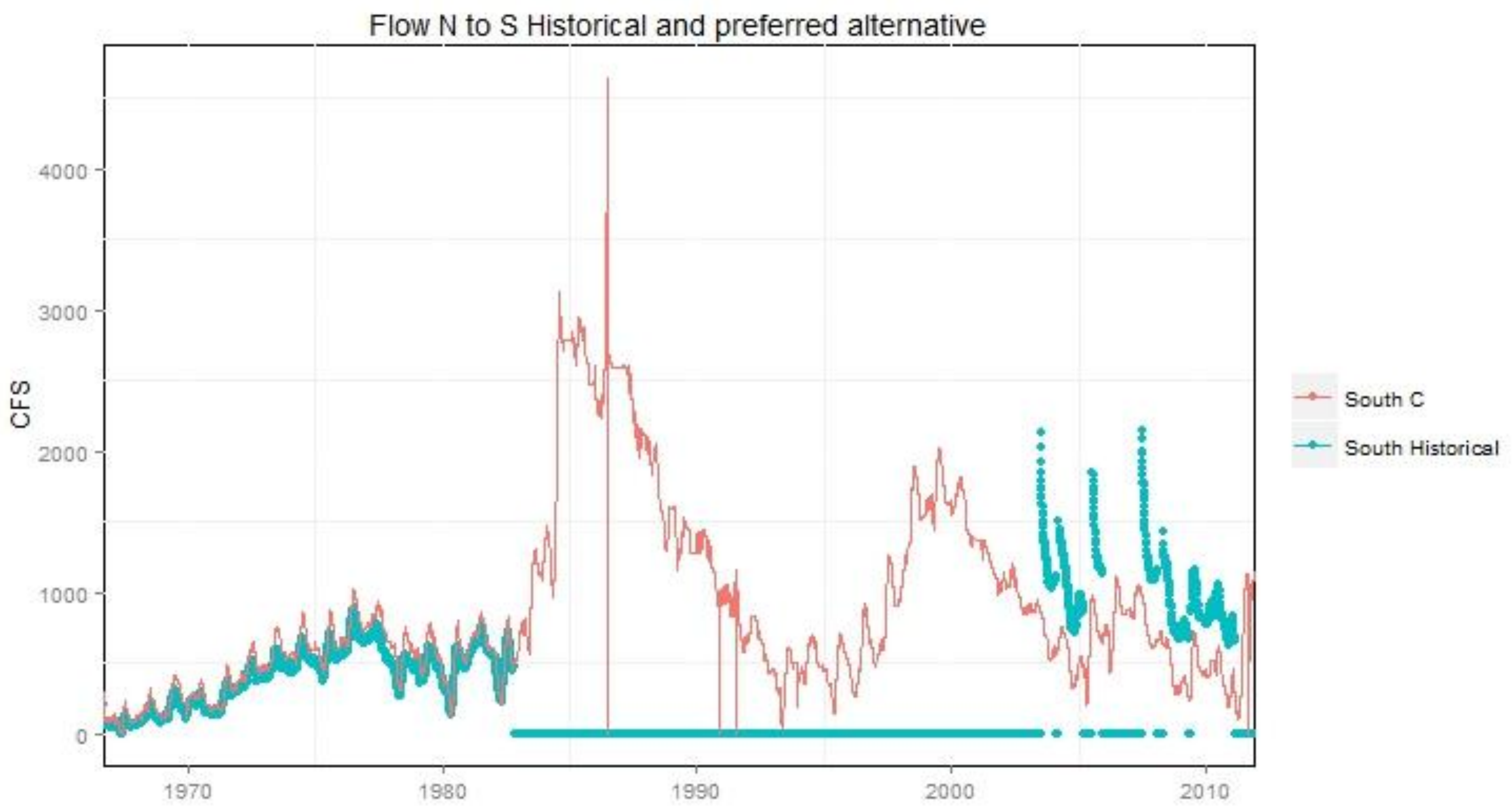
Additional bridge designs



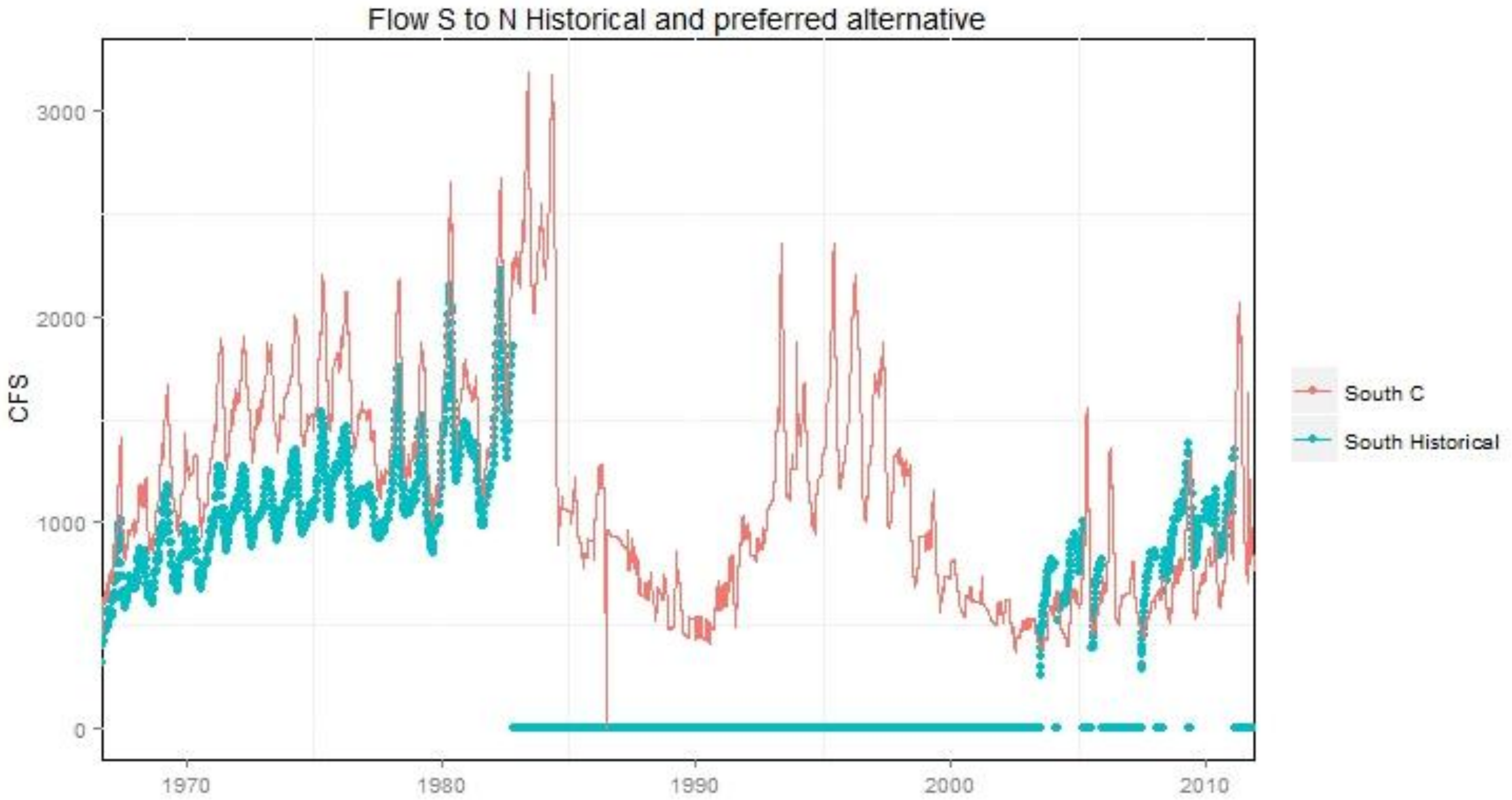
Additional bridge designs



Additional bridge designs



Additional bridge designs



Future Work

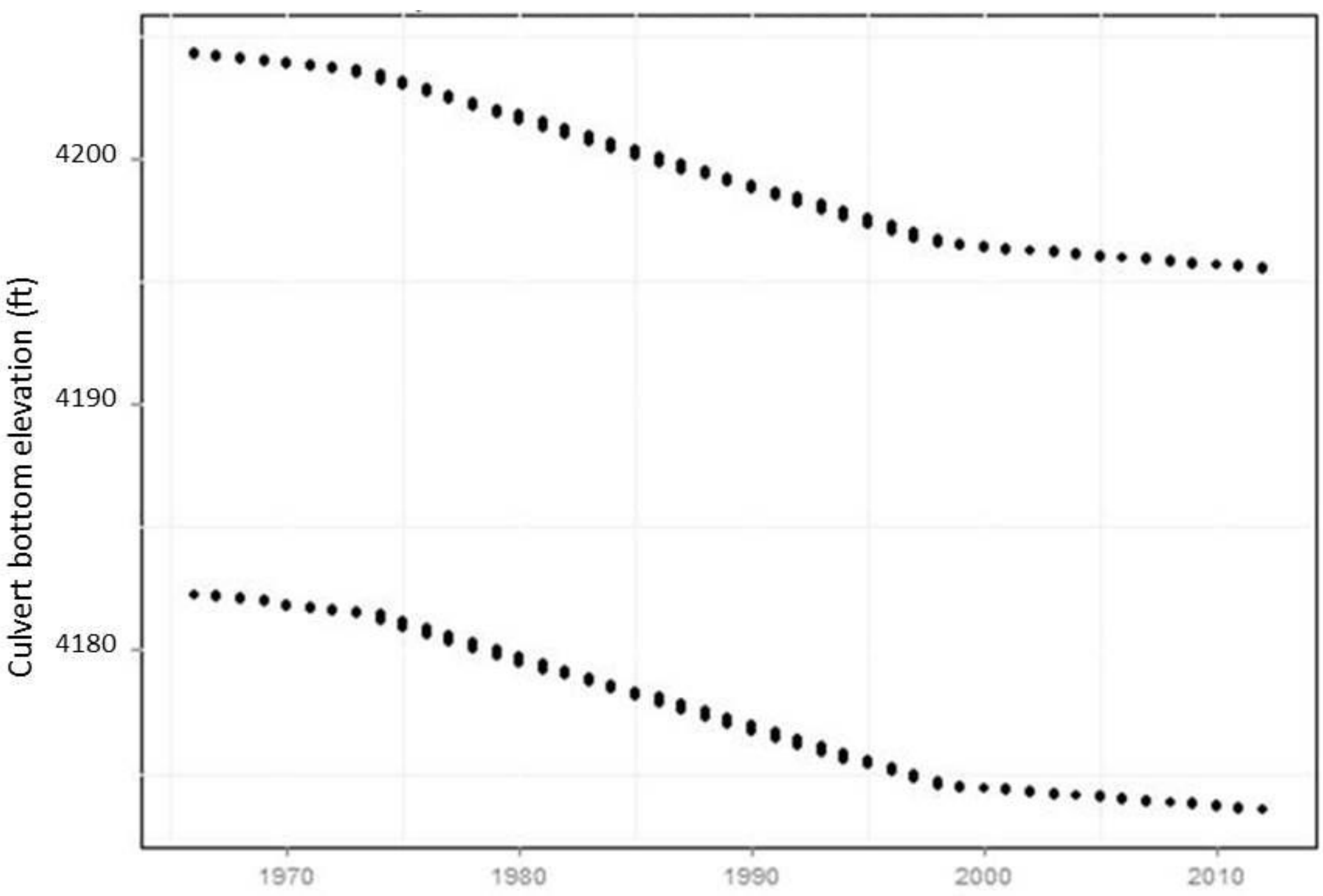
- More accurately model period of submerged culverts
- Submit paper for peer-review publication
- Incorporate climate variability to better understand context of past 60 years
  - Wet period? Dry? Average?
- Incorporate climate change projections to more accurately model future scenarios
- Incorporate ecological studies to evaluate changes to brine shrimp habitat
- Validate flow calculations through breach and future bridge

Acknowledgements

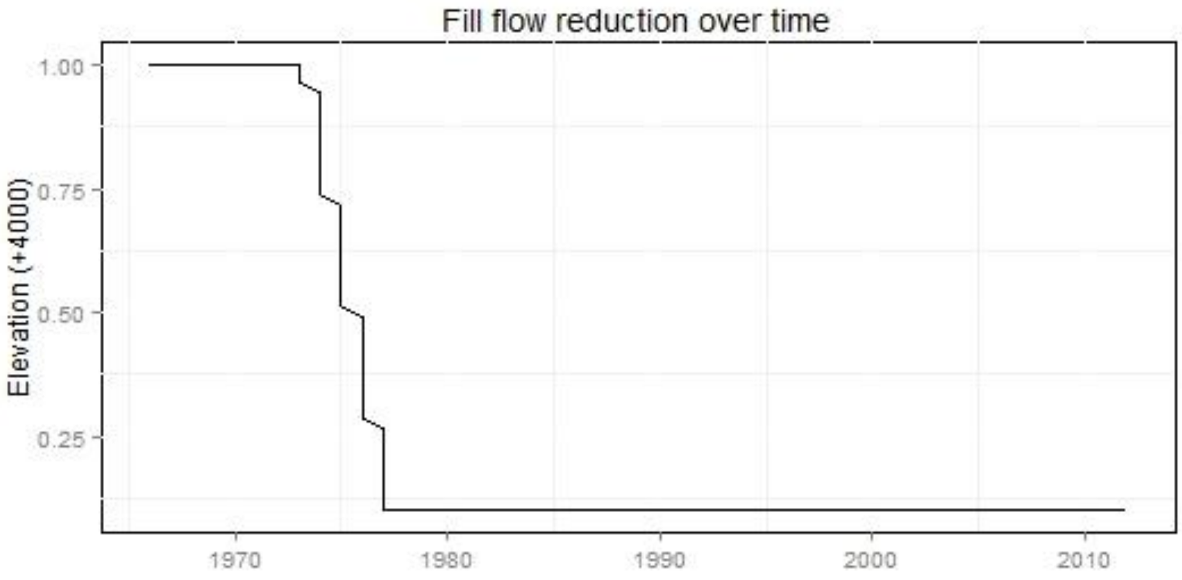
- Funding provided by Utah Department of Natural Resources – Forestry, Fire and State Lands
- Co-authors
  - Dr. Sarah Null
  - Dr. David Tarboton
- Additional Support
  - Dr. Wayne Wurtsbaugh

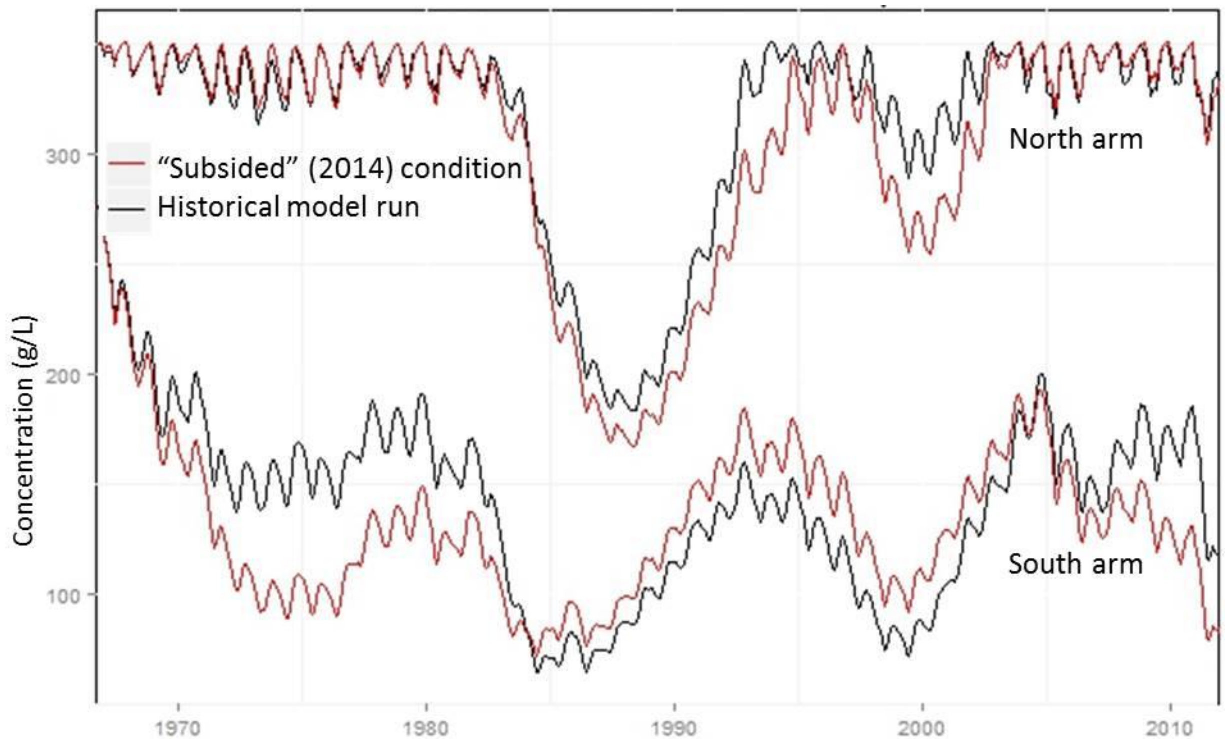
Questions

James White
whitej33@gmail.com

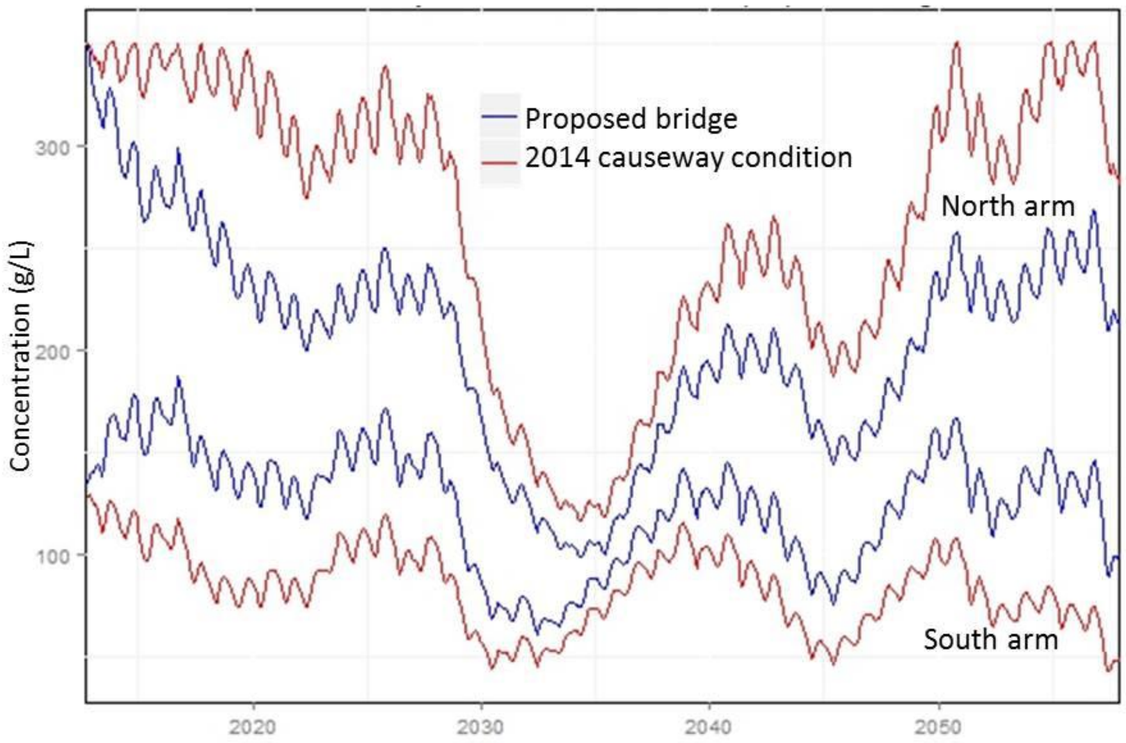


Culvert bottom elevation (ft)
4200
4190
4180
1970
1980
1990
2000
2010


Fill flow reduction over time
Elevation (+4000)
1.00
0.75
0.50
0.25
1970
1980
1990
2000
2010



"Subsided" (2014) condition
Historical model run
North arm
South arm
Concentration (g/L)
300
200
100
1970
1980
1990
2000
2010


Proposed bridge
2014 causeway condition
North arm
South arm
Concentration (g/L)
300
200
100
2020
2030
2040
2050